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A circuit board and a method for its manufacture

The present invention relates to a circuit board with at least one substrate layer and at least one optical channel. The invention also relates to a method for manufacturing a circuit board, in which the circuit board is provided with at least one substrate layer and at least one optical channel. The invention further relates to a method for manufacturing a layer of a circuit board in a continuous process, in which the circuit board is provided with at least one substrate layer and at least one optical channel.

It is known to manufacture circuit boards in which optical signals are transmitted in addition to electrical signals. The transmission of the optical signals is arranged either by means of separate optical components, such as optical fibres, or the circuit board is provided with optical circuit board layers, optical waveguides or the like, which are used to transmit optical signals between optical transmitters and receivers. The materials used for the substrates of the circuit board include *e.g.* a glass fibre polyimide sheet, a PTFE sheet or a glass fibre epoxy sheet. The circuit board is provided with optical waveguides for example by engraving a groove on the surface of the circuit board and providing it with an optical channel *e.g.* by casting a melt mass in the groove, which mass is solidified when cooled and becomes photoconductive. One problem in such an arrangement is that the thermal expansion coefficient of the optical channel may be significantly different from the thermal expansion coefficient of the circuit board. Thus, variations in the ambient temperature may cause stress states between the optical channel and the circuit board. Furthermore, when applying arrangements of prior art, it is difficult to attach optical transmitters and optical receivers to be connected with the optical channel, as well as to achieve the transmission of the optical signal between the optical channel and the optical transmitter and the optical receiver with as small losses as possible.

It is an aim of the present invention to improve the prior art and to provide a method for manufacturing a circuit board as well as a circuit board. The invention is based on the idea of providing the circuit board with at least one plastic layer and providing it with at least one optical channel. To put it more precisely, the circuit board according to the present invention is primarily characterized in that at least one substrate layer of the circuit board is made of plastic, and in the shaping of the substrate layer, a mould has been used, that the substrate layer is provided with a shape which substantially corresponds to the shape of the optical channel, and that the optical channel is formed in said shape provided in the substrate layer. The manufacturing method according to the present invention is primarily characterized in that at least one substrate layer of the circuit board is made of plastic, and for shaping the substrate layer, a mould is used, by which the substrate layer is provided with a shape which substantially corresponds to the shape of the optical channel, and that the optical channel is formed in said shape provided in the substrate layer.. The method for manufacturing a circuit board in a continuous process according to the present invention is primarily characterized in that at least one substrate layer of the circuit board is made of plastic, and for shaping the substrate layer, a mould is used, by which the substrate layer is provided with a shape which substantially corresponds to the shape of the optical channel, and that the optical channel is formed in said shape provided in the substrate layer.

The present invention shows remarkable advantages over solutions of prior art. In the circuit board according to the invention, the thermal expansion coefficients obtained for the optical channel and the circuit board are substantially equal, wherein variations in the temperature do not significantly cause stress states in such a circuit board. Furthermore, the coupling of the signal obtained between the optical channel and the optical transmitter/receiver is efficient, because the design of the channel and the coupling element (*e.g.* a bevelled surface) can be provided already in the mould design, wherein the channel is provided with the desired shape without separate work stages during the manufacturing. Furthermore, the material of the substrate can be selected so

that it meets the requirements for the cladding of the optical channel, thereby making it possible to exclude a separate cladding and to provide a simpler structure and manufacturing method. Moreover, the optical layer can be used as a substrate for electrical couplings, and a separate intermediate layer will not be needed to join the optical layer and the electrical layer. The use of a thermoplastic as the substrate for the circuit board also provides relatively easy processability, for example, by hot casting, injection moulding and mechanical processing methods. The materials used in the manufacture of the circuit board according to the invention are recyclable. Furthermore, the circuit board according to the invention can be provided with very small-sized electrical and optical microvias between any layers.

In the following, the invention will be described in more detail with reference to the appended drawings, in which

Fig. 1 shows the structure of a circuit board according to an advantageous embodiment of the invention in a top view,

Fig. 2 shows the structure of an optical channel in a reduced cross-sectional view,

Fig 3a shows, in a reduced cross-sectional view, the structure of a circuit board according to a third advantageous embodiment of the invention, implementing an advantageous structure of the optical channel,

Fig. 3b shows, in a reduced cross-sectional view, the structure of a circuit board according to a fourth advantageous embodiment of the invention, implementing another advantageous structure of the optical channel,

Fig. 3c shows the structure of a circuit board according to yet another advantageous embodiment of the invention, in a top view,

Fig 4a shows the structure of a circuit board according to yet another advantageous embodiment of the invention, in a top view, and

Fig. 4b shows the structure of the circuit board of Fig. 1a in a reduced cross-sectional view at the location A–A.

In the following example, we shall describe the steps of the manufacturing method according to an advantageous embodiment of the invention for manufacturing a circuit board 1 according to Figs. 1a and 1b. It is obvious that the example showed herein is only one possible circuit board structure, but in practical applications, it is possible to implement very different circuit boards. To illustrate the invention, Fig. 1a only shows some components 7, 8, 9 as well as optical channels 3 and electrical wirings 5. The number of layers as well as components to be placed on the circuit board may vary in practical applications.

Figure 1 shows a circuit board structure consisting of a conventional substrate layer 2 equipped with wirings 5 and optical channels 3. We shall next describe the steps for manufacturing the circuit board 1 in a reduced manner. The substrate layers 2 of the circuit board according to the present invention are made of a thermoplastic (thermoplastic resin) by casting. For this purpose, a cast mould (not shown) is made and provided with the shape desired for the circuit board as a negative mould. The example circuit board of Fig. 1 is provided with an optical channel 3 in connection with the substrate layer 2. This can be implemented in a variety of ways. One way is to engrave the shape desired for the optical channel 3 on the surface of the circuit board after the forming of the substrate layer. Next, melt plastic or another substance that is in viscose state and is photoconductive after solidifying, is cast onto the engraved point. Thus, the solidified substance forms the desired optical channel 3. Another possibility is to implement the optical channel in connection with the manufacture of the substrate layer. Thus, the manufacturing mould for the substrate layer 2 is advantageously equipped with a negative pattern which is detachable from the mould and which corresponds to the shape desired for the optical

channel, or two moulds are made which are otherwise substantially identical but one of them does not have the shape to form the channel, such as a ridge. In this case, melted plastic is first cast in the cast mould to make the substrate layer, after which a space is formed for the optical channel 3 in the substrate layer 2. Next, the mould is changed or the substrate layer is transferred to another mould so that the optical channel can be made by casting/injecting a plastic suitable for forming the optical channel in the mould. After this step, when the plastic that forms the optical channel has also been solidified, the substrate layer 2 is finished and also includes the optical channel 3.

The use of thermoplastic also makes it possible to use injection moulding in the manufacture of a circuit board to be provided with one or more optical channels. In two-component injection moulding, a first component (e.g. melted thermoplastic to form the substrate layer) is first injected into the mould along a first passage to die. The first component is then allowed to cool down, after which the mould is changed and the second component (*e.g.* melted thermoplastic to form the optical channel) is injected along a second passage to die. After the second component has sufficiently cooled down, the mould can be opened and the finished piece (circuit board or one of its substrate layers) can be removed from the mould.

For the channel, the substrate layer 2 can also be provided with a recess by the hot pressing technique using a mould as well, for example a steel mould. The surface of the mould has been worked to provide it with a structure reversed from the surface structure desired for the substrate layer, *i.e.* the negative of the surface structure. The substrate layer 2 is formed by hot pressing of a circuit board preform made of a thermoplastic or thermosetting plastic prepreg (partly cured thermosetting plastic preform), wherein the mould or the circuit board preform is heated to improve the formability of the circuit board preform. After this, the mould is pressed against the circuit board preform, wherein the surface pattern of the mould is copied reversely onto the surface of the circuit board preform. The circuit board preform is cooled, after which the surface of the circuit board can be supple-

mented, if necessary, *e.g.* by adding optical medium at the points where optical signal passages, or optical channels 3, are to be made. Consequently, these optical signal passages 3 are implemented by providing the mould with a corresponding embossing. Naturally, the method can also be reversed so that instead of grooves, the substrate is provided with ridges, along which the optical signal is to be conducted. Thus, in a corresponding manner, the mould is equipped with grooves which are then copied negatively onto the surface of the substrate.

The mould used for making the substrate layer 2, as well as one or more optical channels 3 to be formed therein, can be provided with very specific details. This makes it possible to provide the optical channel with versatile optical properties. The mould can be used to make relatively accurately, for example, a diffractive or refractive surface grid, in which the finest details have a size smaller than one micrometre. Moreover, by the method of the invention, the structures required for reversing the optical signal (a mirror, a surface grid, *etc.*) can be implemented at the end points of the optical channel. For example, Fig. 2 shows, in a cross-sectional view, the structure of an optical channel in which these structures 4 for reversing an optical signal can be seen at the end points. In this example, the reversing structures 4 are implemented as bevellings at the end points of the optical channels, but also other shapes can be used, such as a curved shape with a focus, for example, at the level of the surface of the substrate layer 2 or slightly outside it. When an optical transmitter or an optical receiver is placed at this point, it can be positioned very close to said focal point, so that in some cases the optical signal losses may be smaller than in the case of the bevelled mirror structure. If necessary, the surface of the reversing structure 4 can be treated to reflect the optical signal, for example by coating the surface of the circuit board preform moulded in the mould, with a suitable material to reflect optical signals at the reversing structure 4. However, the coating must be provided before the optical channel is filled with an optical medium.

In some cases, the optical channel 3 is made to comprise a core layer lined with a so-called cladding. The refractive indices of the core layer and the cladding differ from each other so that a beam travelling diagonally in the core layer will not penetrate the cladding but is reflected back towards the centre of the core layer, unless the angle of incidence is greater than the critical angle. Such a structure is also called a core-cladding structure. To provide such a structure, the optical channel is made in *e.g.* two steps so that the cladding is cast in the first step and the core layer to be formed in the cladding is cast in the second step. Figure 3a shows an example of such a structure. To ensure the best optical function, the cladding should line the core layer throughout, seen in the direction of the cross-section of the optical channel, so that the optical signal would remain better inside the core layer. It is thus advantageous and in some applications even necessary to include an optical layer both above and below the structure of Fig. 3a. The refractive index of this optical layer to be added should be as close to the refractive index of the core layer 3.1 as possible. However, by the method of the invention, the optical channel, in which the core layer is lined with the cladding in the cross-sectional direction, can also be made in another way than by adding the optical layers. This is achieved, for example, by forming parts of the optical channel in several substrate layers which are placed on top of each other. For example, with three substrate layers placed on top of each other, it is possible to provide *e.g.* an optical channel with the cross-section shown in Fig. 3b, in which the first 2.1 and third 2.3 substrate layers are provided with a cladding 3.1 of the optical channel 3, and the second substrate layer 2.2 placed between these substrate layers 2.1, 2.3 is provided with the core layer 3.2 of the optical channel 3, which is further lined with the cladding 3.1. Another possibility is to make the channel slightly larger and to apply the cladding at the edges of the channel, for example, by spinning before the casting of the core and, onto the channel after the casting of the core. In this way, the whole channel can be implemented in a single layer. The third alternative is to make the substrate of the cladding material, wherein after the pressing and the filling of the core, it will only suffice to apply the upper cladding by *e.g.* pressing or spinning.

The above-described multi-layer structure can also be applied in the transmission of optical signals between the substrate layers *e.g.* in the following way. The point where optical signals are intended to be transferred between layers is provided with the structures (bevellings, grids, or the like) of these substrate layers for reversing the signal into the optical channel. This is shown in the appended Fig. 3c, in which optical signals are transferred from the first substrate layer 2.1 through the second substrate layer 2.2 into the third substrate layer 2.3. The reversing structures 4 are provided both in the first substrate layer 2.1 and the third substrate layer 2.3. At the corresponding point in relation to the surface of the substrate layer, the second substrate layer 2.2 is provided with a substantially transverse optical channel 3.3 which is formed *e.g.* by making a hole in the circuit board preform used in the manufacture of the second substrate layer 2.2 and filling it with an optical medium.

Figures 4a and 4b show yet another advantageous circuit board which has been made by the method according to the invention. The circuit board comprises a substrate layer 2 which is provided with an optical channel 3. In this example, the optical channel 3 is substantially elliptical in the direction of the plane of the circuit board 1. The ellipse has two focii 6.1, 6.2. The focii 6.1, 6.2 are provided with reversing structures 4.1, 4.2 by which the direction of the optical signal is changed by about 90°. The reversing structure 4.1, 4.2 has advantageously substantially the shape of *e.g.* a circular cone or a straight bevelling. For example, an optical transmitter 7 is placed in connection with the first focus 6.1. From this optical transmitter 7, optical signals are transmitted which are directed towards the surface of the circuit board, into the first reversing structure 4.1. This first reversing structure makes the optical signals turn substantially in the direction of the optical channel. Because the first reversing structure 4.1 is placed as precisely as possible in one focus of the ellipse, the optical signals travel in the optical channel to the second focus 6.2 defined by the elliptical shape. In connection with this second focus 6.2, there is a corresponding second reversing structure 4.2 which turns the optical signals entering the

second focus by about 90°; in other words, they are directed substantially transversely to the surface of the circuit board, away from the optical channel, to the optical receiver 8 placed at the second reversing structure. When arranged in this way, it is possible to transfer optical signals from even strongly diverging sources with relatively small losses in the optical channel 3 formed in the circuit board 1.

According to the invention, the circuit board shown in Figs. 4a and 4b can be made by *e.g.* the hot pressing technique. Thus, a mould is made, in which the surface structure of the circuit board preform is implemented in a reversed manner. Thus, at the point of placing the substantially elliptical optical channel, a bulge is provided, whose edges have a shape which is as close to elliptical as possible. In a corresponding manner, a pit having substantially the shape of a circular cone is provided at the focii 6.1, 6.2. After the pressing, the circuit board preform is provided with a pit having substantially an elliptical shape, and each focus of the elliptical form is provided with a bulge having substantially the shape of a circular cone. These bulges at the focii are coated with a reflective coating, after which the elliptical pit can be filled with an optical medium to form the optical channel. If necessary, the channel can also be formed as a separate part which is attached to the recess for example by glueing, by welding or by another fixing mechanism. This also makes it possible to implement a coupling element as a recess on the bottom of the channel, wherein a void air pocket is formed underneath the bevelling. The plastic/air interface of the bevelling makes a totally reflecting mirror structure possible, having an excellent coefficient of performance and requiring no coating or the like.

The circuit board according to the invention can also be made by manufacturing one or more substrate layers of an optical material. This optical substrate layer can then be provided with *e.g.* grooves at the optical channels. These grooves are filled with another optical material whose refractive index is different from the refractive index of the substrate layer to form the above-described core-cladding structure. The cladding thus consists of the whole substrate layer. This alternative has

the advantage that the substrate layer does not need to be equipped with a separate cladding.

As already stated above in this description, thanks to the hot pressing technique, injection moulding and other methods for manufacturing and processing thermoplastics and the use of thermoplastics as the substrate material for a circuit board, it is possible to provide very specific details in the circuit board. Thus, the shapes and the placement of the geometrical shapes of the above-described type are very precise, which makes it possible to implement optical applications which are better and have smaller losses than those of prior art in connection with the circuit board in the same manufacturing process.

Substrate layers 2 made by the method of the invention can be placed on top of each other to manufacture multi-layer circuit boards. Optical channels may be present in one or more substrate layers 2 of the multi-layer circuit board. The precise manufacturing process makes it possible to form *e.g.* very small microvias in such a multi-layer circuit board. Microvias can be formed between any layers, for example between two or more inner layers and/or between the surface layer and an inner layer and/or between surface layers. Thanks to the relatively low melting temperature of thermoplastics, the multi-layer circuit board can be fabricated layer by layer so that electrical components may be placed in the substrate layers, which has not been possible because of the relatively high temperatures used in the manufacturing techniques of conventional circuit boards.

The manufacture of the substrate layers 2 of the circuit board 1 by means of a mould makes it possible to produce large batches with the same mould. In this way, small production tolerances are achieved. Furthermore, particularly in the hot pressing technique, it is possible to apply continuous pressing methods, such as so-called reel-to-reel techniques, wherein the circuit board preform is fed from a reel to a mould for embossing. After the embossing in the mould, the finished circuit board preforms can be reeled to another reel, from which the

circuit board preforms can be cut in a separate process or even laminated with other layers to form a multi-layer board.

The substrate layer 2 can also be coated with a metal to form electrical wirings on the surface of the substrate layer 2 in addition to the optical channel structures. The metallizing can be made for example by evaporating and/or depositing *e.g.* a copper or aluminium layer onto the substrate layer 2, either before or after the formation of the optical structure. The circuitry pattern can be made either in a subtractive process, in which the surface of the substrate layer 2 is first metallized substantially throughout, or in an additive process, in which the surface of the substrate layer 2 is first provided with a mask to define the desired circuitry pattern. After the application of the mask, the metal layer is applied, wherein the metal layer is only formed at such points on the surface of the circuit board which are not covered with the mask. Yet another possibility for forming the circuitry patterns is to use *e.g.* the screen printing technique. In this case, screen printing is used to print the circuitry pattern onto the surface of the substrate layer 2. If necessary, this printed circuitry pattern can be grown by *e.g.* electrolysis.

The manufacture of the circuit board 1 can be performed layer by layer, making each circuit board layer (substrate layer 2) separately so that, for example, the desired circuitry pattern is formed on the conductive layer on one side of each substrate layer in, for example, an etching process. The substrate layers are stacked on top of each other, and a non-conductive layer (not shown in the appended drawings) is placed between each substrate layer. The purpose of this non-conductive layer is to prevent a short circuit between the wirings on adjacent substrate layers and, on the other hand, to attach the substrate layers to each other. In the non-conductive layer, for example the same material is used as in the substrate layers but which has not been fully cured yet. If an optical layer covering substantially the whole circuit board is formed between two substrate layers to be placed on top of each other, a non-conductive layer is not necessarily needed between the

substrate layer and the optical layer, but the optical layer is used as the non-conductive layer.

For the electrical coupling between the transmitter 7 and the receiver 8, the necessary wirings 5 are connected to the transmitter 7 and the receiver 8. For the sake of clarity, Fig. 1 only shows some of these wirings.. The figure shows the control circuit 9 for the transmitter 7, where the generated electrical control signals are conducted via the wirings 5 to one or more pins 7.1 to be used for the control of the transmitter 7.

The optical transmitter used can be suitably, for example, a semiconductor light source, such as a semiconductor laser, a light emitting diode (LED), or the like. One advantageous semiconductor laser to be used in connection with the invention is the so-called vertical cavity surface emitting laser (VCSEL). In such a semiconductor laser, the direction of light emission is the direction perpendicular to the surface, *i.e.* substantially transverse to the installation substrate of the semiconductor laser. Thus, the emitted light can be easily directed to *e.g.* the reversing structure 4.

By the method of the invention, it is also possible to implement three-dimensional structures. The circuit board implemented by the method of the invention can also be used as a device housing or as a part of one. Such an application is provided with the necessary substrate layers 2 which are equipped with the electrical wirings and optical channels. The folding of the circuit board into the shape required by the housing can be implemented by means of a mould which is also used to construct the other necessary surface patterns. At least the outermost layer is thus a thermoplastic layer with the desired appearance and shape of the device housing. The outermost layer may also be provided with optical channels for producing *e.g.* ornamental light patterns, for implementing lighting of keys and/or a display, *etc.* Furthermore, the housing may be equipped with a window made of an optical medium in such devices in which a display is used for displaying information to the user of the device. The window does not need to extend

through the whole housing, but the display may be attached directly to one of the substrate layers of the circuit board forming the housing. The substrate layers applied onto this substrate layer are provided with an opening, and *e.g.* the topmost substrate layer is equipped with the window.

In the circuit board of the invention, one or more substrate layers 2 may also be entirely used as the optical layer. The surface of this optical layer may also be directly provided with wirings, if necessary.

It is obvious that the present invention is not limited solely to the above-presented embodiments but it can be modified within the scope of the appended claims.